Low Cost, Hermetic Optical Port Using Liquid Crystal Polymer

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1.0 Hermetic Packaging

Hermetic packages are used for electronic & opto-electronic components and micro electro-mechanical systems (MEMS) to protect the internal components from potentially corrosive or otherwise damaging elements such as water vapor and oxygen. Typically hermetic packages are formed using materials such as metals, ceramics or glass, since these are highly impervious to corrosive vapors or gasses. Input and output ports pose the greatest problem, since these represent a breach of the external casing. For electrical ports, where electrical insulation is required, the conductors are generally fed through glass insulating beads which are then soldered to the metal cover. In the case of optical ports, where glass fibers must enter the package, the fibers must first be metalized, and then sealed by soldering. Both these operations are time consuming and costly, and add significantly to the complexity of the overall packaging.

A generally accepted test of the hermeticity of a package is the Telecordia damp heat test, in which the device is required to survive 1000 hrs at a temperature of 85^0 C. and 85% relative humidity. Polymers are used extensively in the electronics industry for less demanding packaging applications, but most common polymers do not exhibit the necessary barrier properties required for hermetic packaging.

Recently, a new class of polymeric materials, liquid crystal polymers (LCP), have been shown to exhibit excellent moisture and oxygen barrier properties. LCPs are polymers that contain rigid crystalline molecular chains interconnected by more flexible segments. When LCPs flow in the molten or solvated state the rigid molecular chains tend to align mutually like logs in a river. It is the rigidity of the molecules combined with the tight packing that gives rise to the high strength and low permeability of these materials. LCPs also exhibit many other properties, physical, electrical and chemical, that make them very attractive candidates for packaging. These properties are described in more detail below.

2.0 Properties of LCP

Not only are LCPs highly impervious to moisture, but as a result of the tightly packed crystalline nature, the interstices allow very little absorption of moisture or other gasses. Consequently, out-gassing, which is a problem for many polymers, is reduced to insignificant levels. Further, since LCP is merely heated to become fluid, there is no need to use solvated LCP, which eliminates another major source of outgassing. The moisture absorption and transmission properties of LCPs are compared with other polymer classes in Table 1. From the table we can see clearly that LCPs offer very significant improvement both in terms of moisture absorption and transmission.

Table 1: Comparison of barrier properties of different polymer classes

Polymer class	Specific polymer	Moisture absorption (% @73^0 F, 50% relative humidity, per day	Moisture transmission rate (gm/m^2/day/atm./mil
Polyester	PET (poly ethylene terephthalate)	0.06 (immersion)	28
Fluorinated polymer	PVDF (Polyvinylidene fluoride, Dupont TTR10AH9)	0.5	5.3
Polyamide	Nylon	1.2	
Liquid crystal polymer	Vectran 200P (made by Tecona)	0.02	0.17
	Zenite (made by Dupont)	0.002 0.05 (6 mth. Immersion)	

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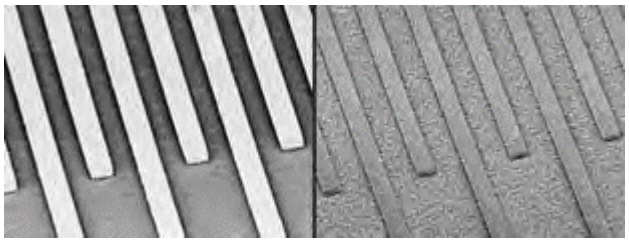

Figure 1: Scanning electron micrographs of metal traces of LCP circuits made on a) a laminate substrate and b) a vapor-metallized LCP film (from "Liquid Crystal Polymers – a flex circuit substrate option," Rui Yang, Advanced Packaging, March 2002).

LCPs are thermoplastic so that there is a intermediate temperature such that the LCP is made fluid without break down of the crystal structure. They typically melt at about
280^0 C and are thermally stable to 350^0 C. The coefficient of thermal expansion (CTE) is very low, and highly anisotropic, being lowest in the direction of molecular alignment. The actual bulk value of the CTE can therefore be controlled to some extent by either controlling the degree of orientation, or by laminating layers with orthogonal orientations. This is a desirable feature, since it means that the CTE can be matched to
that of the substrate material, thus significantly reducing stress associated with thermal cycling.

LCPs also exhibit very little creep. This means that microscopic features produced by molding, embossing or other such processes will retain their sharp edges and dimensional stability. Complex packaging designs are therefore possible, in which finely detailed features can be defined to locate, align and secure the various optical and opto-electronic components. Complex structures have been written in LCP films using lithography as shown in Figures 1.

LCPs have a low dielectric constant and loss factor from 1 kHz to 45 GHz. For instance copper clad Biac LCP, sold by W. L. Gore for flex circuit applications, has a dielectric constant of 3.0 and a loss tangent of 0.003 from 3 to 45 GHz.

What is less well known is that LCPs also have better radiation resistance than almost all other class of polymers. Table 2 compares the gamma and UV radiation hardness of several classes of polymers. LCPs have excellent radiation resistance. Acrylates and fluoropolymers also have good radiation hardness. However, acrylates are very susceptible to moisture while the moisture barrier properties of fluoropolymers are a factor of 30 worse than LCPs.

Table 2: Radiation hardness comparison of polymer classes

Base Resin	Gamma Radiation	UV Radiation
Nylon 6/6	F	P
Polyethylene terephthalate, PET	G	F
Acrylates, PMMA	G	G
Polyvinylidine Fluoride, PVDF	G	G
Liquid Crystal Polymer	G	G

Ratings:
E= Excellent; G= Good; F= Fair; P= Poor (Data from RTP Imagineering Plastics)

3.0 Thermal Bonding of LCP to Glass Substrates

Ticona sells extruded LCP films with thickness ranging from 2 mil to 10 mil under the trade name Vectra. We acquired sample sheets of 10 mil thick Vectra (A950). Thermal bonding experiments were perform by placing pieces of LCP film between two heated glass slides and applying external pressure for a fixed period of time. A simple apparatus was designed and assembled to generate the thermally bonded samples. Sections of Rogers Zyvex film were cut out with dimensions of about 4" by 0.5". These films

have copper cladding on one side. Soda lime microscope glass slides, 3"x 1" x 1mm, were acquired from VWR Scientific. A sandwich was formed using two glass slides and a length of the Zyvex section in the middle as shown in Figure 2.

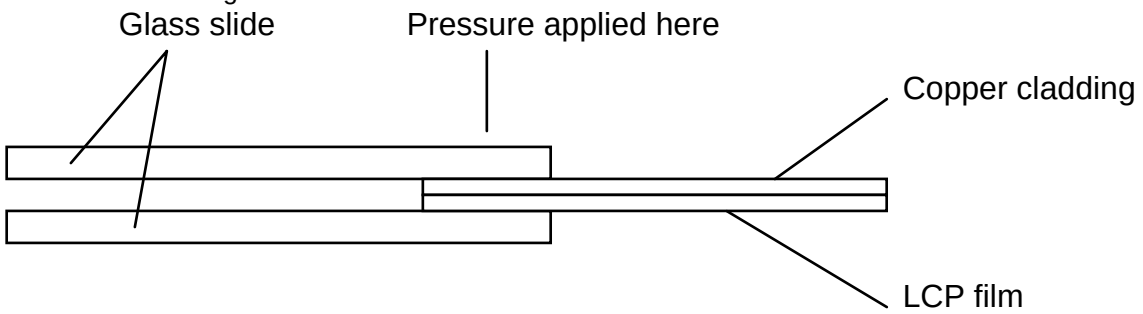

Figure 2. Schematic showing glass slides and LCP laminate in the middle.

180^0 pull strength tests were performed on the generated glass/LCP bonds. Copper clad LCP is sold by Rogers and W. L. Gore under the trade names of Zyvex and Biac respectively. Their data sheets quote a 180^0 peel strength of 6 lb/inch for the bond between the copper and LCP. The best thermal bonds between glass slides and Zyvex in our experiments had a 180^0 peel strength of 14 lb/inch. This demonstrates that with the right temperature and pressure conditions sufficiently strong bonds can be generated between LCP films and glass slides.

We acquired 10 mil thick Vectra (A950) samples from Ticona. Thermal bonding experiments, similar to those with Zyvex, were conducted using Vectra A950. A sandwich consisting of 1" x 1" sections of Vectra A950 between two glass slides, was formed and thermally bonded.

4.0 Accelerated life tests performed on thermal bonds

In many cases where lifetime against vapor pressure can be determined by moisture accelerated testing, a linear relation can be found on a log-log graph. In these cases the lifetime, *K*, can be represented as a function of temperature, T, by the equation

$$K = Ae^{\frac{-E_a}{kT}} \qquad (1)$$

where A is a determinable constant, k is Boltzman's constant, T is the temperature in Kelvin, and E_a is the activation energy. Since the relation is exponential K is defined as the reaction rate under the stress determined by the activation energy. It is difficult to measure lifetimes at room temperature since it is expected to be of the order of years. However, if lifetime can be measured at atleast two different elevated temperatures, equation 1 can be used to determine both A and E_a. Equation 1 can then be used to calculate lifetime at any other temperature.

To get the activation energy for the thermal bond between LCP and glass, thermally bonded fixtures were life time tested at 100 % humidity at two different temperatures -- 95^0 C and 116^0 C. The tests at 116^0 C were performed in a domestic pressure cooker in which the environment is clearly saturated with water. The 95^0 C tests were performed in a laboratory type temperature controlled oven inside which the fixture was placed in a sealed bottle with sufficient water to saturate the volume. The fixtures were periodically removed and the bond was tested by trying to pry the glass slides apart by inserting a blade between them. Prior to any testing the bonds are very strong and the glass slide will break before the bond does. However, with increasing exposure to saturated atmosphere at elevated temperature the bond slowly degrades and at some point the glass pieces can be pried apart. The minimum time required for this to happen is the accelerated life time of the bond.

Table 3: Accelerated lifetime of thermal bonds between LCP and glass

Sample #	Temperature (^{0} C)	Relative Humidity (%)	Life time, T_N (hours.)
13	116	100	5.8
18	95	100	34
20 (surface treated)	116	100	10.0

Using numbers from Table 3 in equation 2 we calculate an activation energy of 1.06 eV
Inserting this in equation 1 the bond life, *t*, at any temperature, *T*, and 100 % relative humidity is given by:

$$t = 1.717 x 10^{-13} e^{\frac{12114.3}{T}} \qquad (2)$$

This implies that the bond life at a temperature of 25^0 C and 100 % RH will be 77573 hours or 8.8 years. If the activation energy of the surface treated sample (#20) is the same as that of the other samples its life at a temperature of 25^0 C and 100 % RH will be 15 years. These tests were done at 100 % RH because we did not have access to a chamber where RH can be controlled to an arbitrary value. However, it is well known that 100% RH tests are much more severe than 85% RH since moisture can actually condense along the bond line and significantly reduce lifetime.

5.0 Sealing metal film with LCP cap and measurement of resistance to damp heat

Copper films were deposited on several glass and silica substrates. Soda lime glass slides from VWR international (2" x 2" x 0.060") were used for the glass substrates. Silica substrates (1" x 2" x 1mm) polished on both sides were obtained from Pacific Quartz, Inc. Several glass slides and five silica slides were vacuum coated with 1000 A^0 copper films by Thin Films Research, Inc. The evaporated copper is shiny and remains shiny over several days even when left exposed to atmosphere. Test fixtures were fabricated to cap the copper film on the glass slides with LCP gaskets using thermal bonding as shown in Figure 3.

The thermally bonded samples from Figure 3 were tested for optical reflectivity of the copper film using a He-Ne laser, after fabrication and after been subjected to "damp/heat" in a pressure cooker (116^0 C, 100 % relative humidity). A reference sample of copper on same type of glass slide but without LCP was also measured along with the capped sample. The measurements are plotted in Figure 4. It is clear that with LCP cap prevents degradation of reflectivity for more than four hours in the pressure cooker. From previously reported activation energy measurements this is equivalent to 6 years at room temperature and 100 % relative humidity.

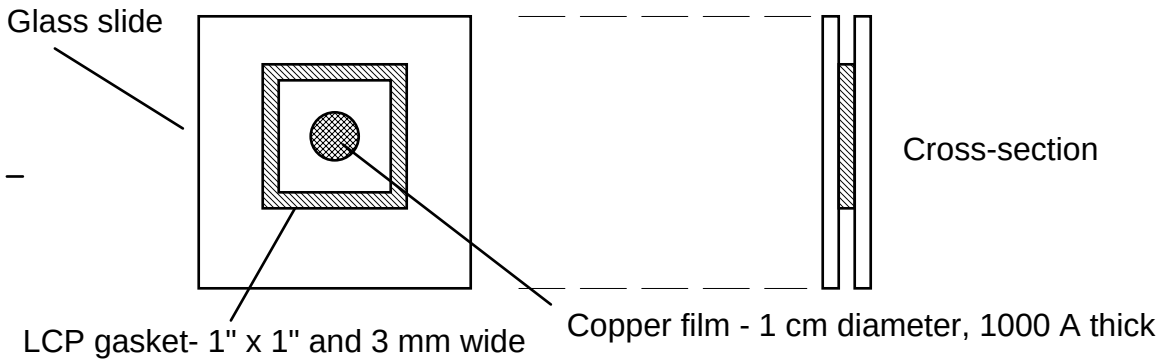

Figure 3 Fixture for LCP capping of copper film on glass substrate.

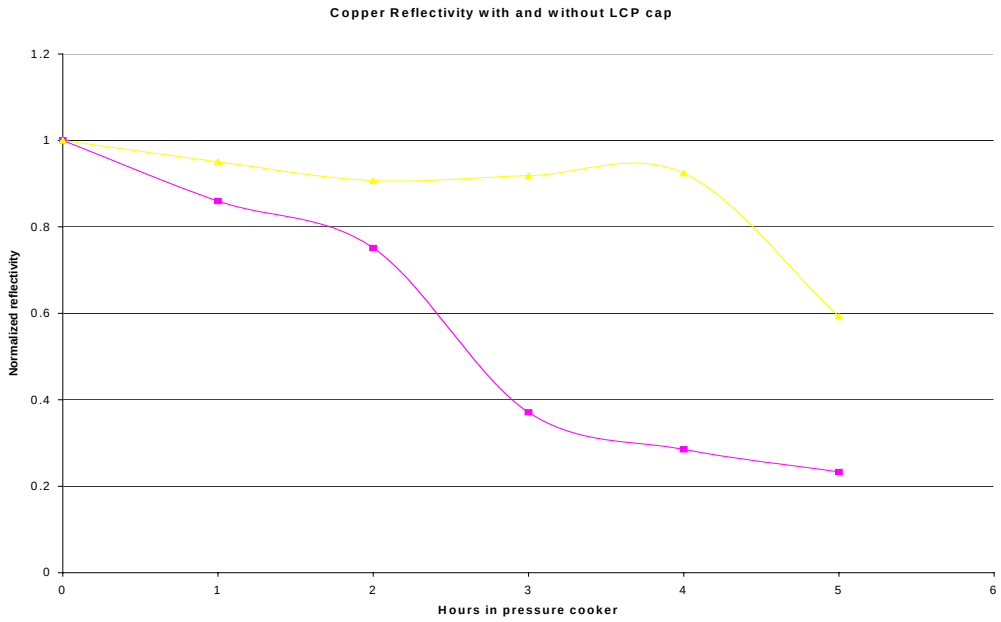

Figure 4 Normalized reflectivity of copper film (normalized to reflectivity at 0 hours); Triangles (sample #35) with LCP cap; Squares (sample #6) without LCP cap.

6.0 Test fixture with silica optical fiber entering and exiting the LCP package

The purpose of this task is to replicate the results of section 5 with opticasl fibers entering and exiting the LCP cap. If metal reflectivity is unaffected with the fibers in place it will demonstrate the feasibility of designing optical ports through LCP cap that will pass “wet/heat” test as required by Telecordia certification. This is equivalent to replacing current, expensive hermetic packaging. To this end several fixtures were fabricated and tested. Figure 5 shows copper reflectivity with and without LCP cap. Again the copper film protected by LCP survives 7 hours in the pressure cooker before the reflectivity of copper is impacted by moisture even with silica fiber entering and exiting the LCP cap.

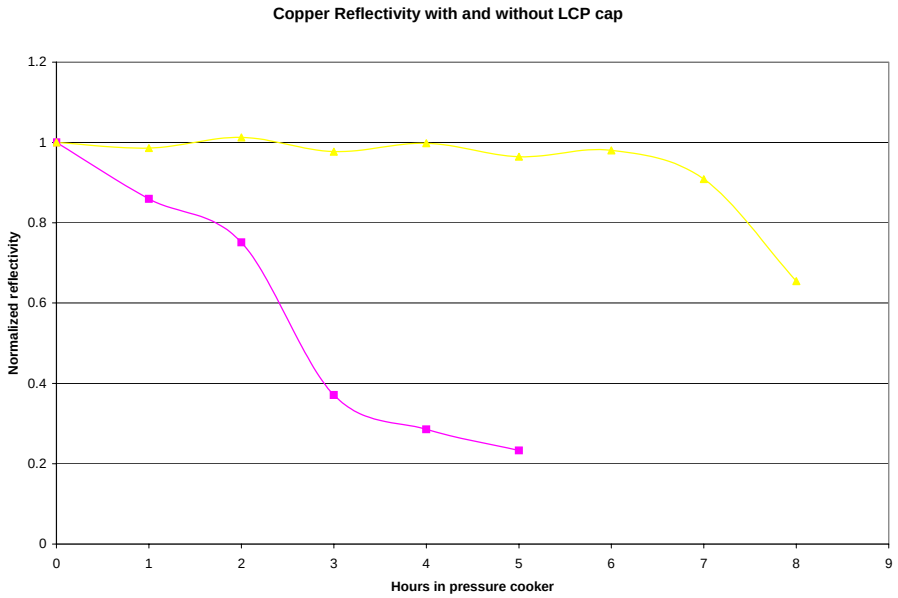

Figure 5. Copper reflectivity without LCP cap(squares) and with LCP cap and fiber (triangles) normalized to value at 0 hrs.

7.0 Summary

We have demonstrated that LCPs can be thermally bonded to insulating substrates with a bond quality that will pass stringent MIL specifications and Telecordia certification. The bond life at room temperature and 100 % humidity will be in excess of 15 years. This bond life can be implemented even with silica optical fiber entering and exiting the
LCP package. To move this technology to the next level of commercialization will require development of bonding techniques such as laser or ultrasonic bonding. This is essential since thermal bonding requires high temperatures that might potentially damage devices on the die that is being packaged.

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